ALUMINUM TREATMENTS TO MODIFY THE SURFACE WETTING PROPERTIES

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Abstract

Different techniques of surface treatments are employed to modify the physical properties of aluminum surfaces. Experimental data report measurements of liquid wetting ability in aluminum surfaces treated with different techniques: lapping, sanding, chemical etching, laser ablation, ion implantation and nanoparticle deposition. Surfaces can be modifies as a function of the different treatment parameters enhancing or reducing the wetting ability. Treatment duration, roughness and morphology play important role in determine the properties from hydrophobic to hydrophilic behavior.

Introduction

Aluminum is the most abundant metallic element on Earth, accounting for approximately 8.5% of the Earth's crust and lithosphere; however, not being an element quite inert, chemically, it can not be found in nature in the free state, but only in combination with oxygen and various minerals, primarily in the form of silicates and aluminum oxide (Al_2O_3) [1]. It is used in every major industry, from the most sophisticated such as electronics or aerospace industry, the most common ones in objects ranging from doors and windows, to car wheels, or horseshoes, and so on.

The vastness of the applications of aluminum is due to the fact that it is a metal with specific technological qualities: lightness, electrical conductivity and thermal characteristics mechanical enhanced by the wide possibility of forming alloys, resistance to weather, plasticity, ductility, durability in contact with food (and almost all the liquid) and, not least, the undisputed aesthetic and color that give the objects made of aluminum, an unmistakable and striking hi-tech appearance [2]. To achieve a good wettability, adhesion and the formation of lasting bonds on the aluminum substrate is important to know the characteristics of the surface by studying the roughness, hardness, morphology and composition of chemical elements. Different physical and chemical treatments can be employed to modify the wetting ability of Al surfaces, such as lapping, sanding, chemical etching, laser ablation, ion implantation and deposition of metallic nanoparticles. In this study the wet ability of the Al surface as a function of different treatments is investigated and discussed.

Materials and methods

Investigations were conducted on pristine pure aluminum obtained by mechanical rolling to a final thickness of 300 microns characterized by a mean roughness of 0.1 μm.

The lapping was obtained mechanically with high-speed rotary polisher up to obtain a mirror finished surface [3]. We have adopted abrasive silicate grains from micrometric to sub-micrometric sized dispersed in a chemical-mechanical polishing solution employed to polish optical components. The parameters used were: speed of rotation 600 r/min; surfaces of parts in contact with the plate, for ring: 100 cm^2; Load: 20 kg; Pressure: 200 g/cm^2.

The sandblasting process has been obtained spraying SiO_2 micrometric particles, less than 10 micron in diameter, accelerated by a fast nitrogen flux to about 100 m/s, against the Al surface in air and they hit the substrate orthogonally to its surface [4]. The treatment time was varied from 30 s up to 3 min.

Chemical etching was obtained using HCl at 10% concentration in water deposited for at room temperature (22° C) for different times from 30 s up to 10 min and just after removed with water [5].

The laser ablation uses a Nd:Yag laser operating at 1064 nm wavelength, acting at pulse energy selectable between 50 mJ and 200 mJ, 3 ns pulse duration, 1 cm^2 spot surface and 10 Hz repetition rate [6].

The ion implantation uses Ar^+ ions accelerated at 2 keV energy and emitted from an ion gun with a current density of 20 $\mu A/cm^2$. Ar^+ ions have been employed to irradiate in high vacuum, at 45° incidence angle, the surface of the pristine Al surface for different times, accumulating different ion doses, from 10^{14} ions/cm^2 up to 10^{16} ions/cm^2 [7]. The evaluation on the ion range and sputtering yield due to the Ar ion implantation treatment was obtained using the international SRIM Code of Ziegler [8].

Nanoparticles were obtained by laser ablation of the different elements in water at the Laser laboratory of plasma physics of Messina University [9]. The used nanoparticles deposited with water drops on the Al surfaces were constituted by Ti, Cu, Ag and Au with a diameter between 50 and 100 nm and a concentration of abut 5 mg/10 ml water. After 24 hours drying, nanoparticles remain deposited on the pristine Al surface.

The method used for the measurement of the angles of wet-ability is the “Sessile drop”: it consists essentially in the measure of the contact angle between the tangent to the profile of a drop, deposited on the sample surface, and the surface itself [10]. The contact angles of 1 μl liquid droplets, deposited on the surface by means of a micro-litre syringe, were measured directly using a webcam aligned to the eyepiece of an optical microscope that records photos of the system formed by the solid sample (housed in a movable sample holder) and the liquid drop. A software permits to measure the wet angle using the line fitting the surface level and the line tangent to the deposited drop in the initial curvature points from the horizontal surface. The contact angle was measured using the formula:

$$\theta = 2arctg(\frac{2h}{d}) \qquad (1)$$

The roughness measurements were performed using a Tencor P-10 surface profiler using a micrometric mobile tip with 1 mg force scanning the sample surface, a scansion length of 500 μm, and a scan speed of 100 μm/s during the scanning of the sample surface. From surface profiles it is possible to determine the surface vertical by equation [11]:

$$R_v = \frac{1}{n}\sum_{i=1}^{n}|y_i| \qquad (2)$$

SEM microscopy was performed by using a 20 keV electron beam, produced by a FEI QUANTA - mod. Inspect S microscope, at the Physics Department of Messina University.

Results

The Roughness profile, the contact angle and the images SEM:

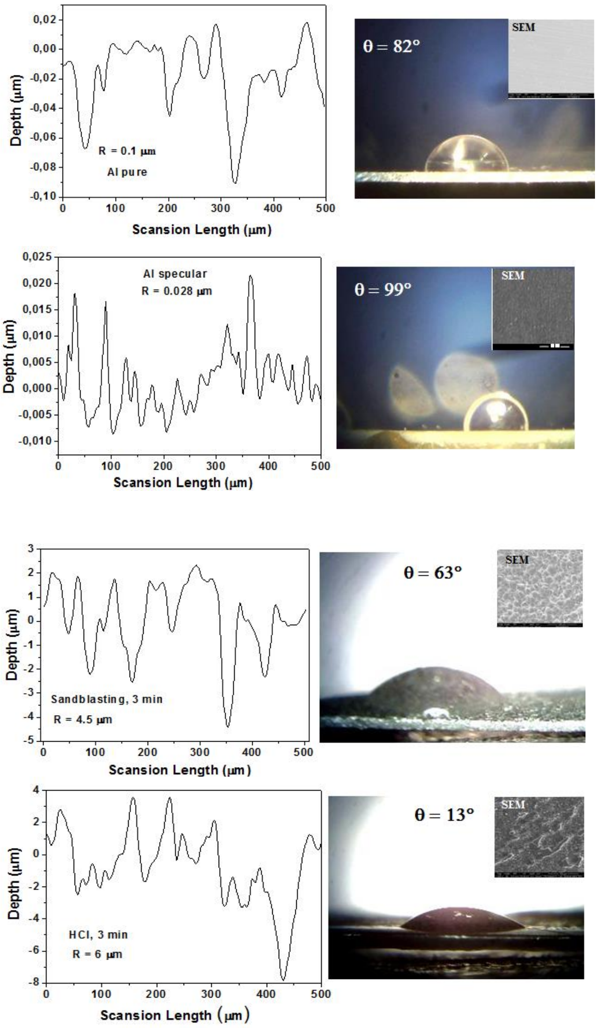
- of the pure aluminum,

- of the Al specular,
- of an Al surface treated using sandblasting for 3 min,
- HCl at 10% in water volume deposited on the Al surface for 3 min,
- of the ablated surface due to 50 laser shots at 200 mJ pulse energy,
- of the implanted surface at a dose of 10^{16} ions/cm^2

are shown in the Figure 1.

The length in the SEM images is the:

- 200 μm for pure aluminum and Al surface treated using sandblasting;
- 100 μm for Al surface treated using Chemical etching HCl;
- 50 μm for Al surface treated using laser ablation;
- 20 μm for specular aluminum.



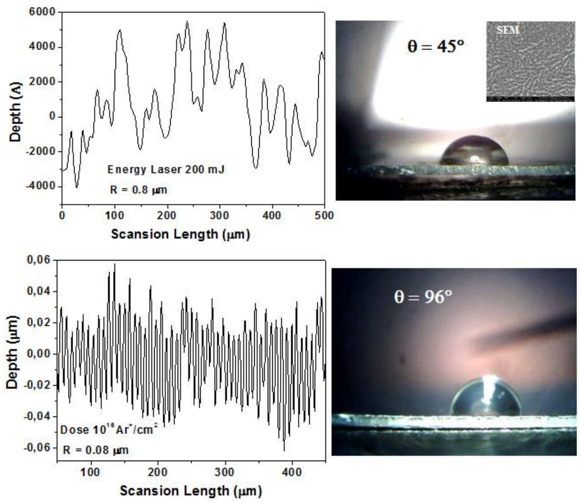


Figure 1: The roughness profile and the contact angle in aluminum surfaces treated with five different techniques; the insert in the picture of the contact angle shows the images SEM.

Figure 2 shown the variation of the angle of contact of the aluminum as a function of the nanoparticles of Ti, Cu, Ag and Au.

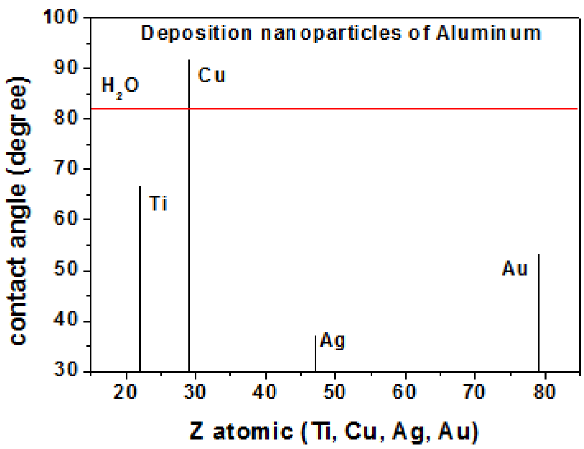


Figure 2: Trend of the angle of contact vs the nanoparticles deposited on the aluminum.

Discussion

The treatment of the lapping increases the contact angle by increasing the hydrophobicity of the surface of Al. In fact, the wetting angle measured at room temperature was 82° and 99° for a pure surface and specular, respectively. The surface profile of the pure Al and Al mirror is rated 0.1 μm and 0.028 μm, respectively.

Al surface treated using *sandblasting* was varied from 30 s up to 3 min. The average roughness is 3 μm and 4.5 μm for 30 s and 3 min sandblasting, respectively, while the contact angle from the initial 82° measured in the pristine surface growths up to 85° at 30 s sandblasting treatment and after decreases up to 63° at 3 min sandblasting, demonstrating that the long treatment increases the hydrophilicity of the Al surface.

The treatment of chemical HCl induces high hydrophylicity of the Al surface infact the wet ability indicating a contact angle decreasing to 75° and 13° at 1 min and 3 min HCl etching. The surface roughness profile which is about 3 μm and 6 μm in the two cases, respectively.

By Laser Irradiation, the ablated surface appears more roughness with respect to the pristine one. At the ablated surface due to 50 laser shots at 50 mJ and 200 mJ pulse energy, the corresponding surface roughness was evaluated to 0.7 μm and 0.8 μm, respectively. The wetting ability for the low energy irradiation and high energy irradiation, at which the contact angle is 92° and 45° for low and high laser energy, respectively, both using an irradiation with 50 laser shots, indicate that low laser energy may increase the contact angle from the pristine value of 82° up to about 92° (using 50 laser shots at pulse energy of 50 mJ); at high laser energy and high shots number the contact angle decreases up to 45°, showing that the laser treatment produces hydrophilicity of the Al surface.

Ion implantation removes atoms from the al surface, especially if the incidence angle is high; generally it reduces the roughness of the Al surface and increases the wetting angle of the implanted surface as a function of the implanted dose, similarly to a polishing effect. Figure 1 shows the roughness profile of the implanted surface at a dose of 10^{16} ions/cm^2, of about 0.08 μm, and the optical image of the wetting ability measurement indicating an angle of 96°.

The treatment with the nanoparticles deposited on the surface of Aluminium (Figure 2) decreases the wettability of water (Ti, Ag, and Au), while in other cases the increases (Cu). In fact the contact angle for Ti, Cu, Ag and Au are of 67°, 91°, 37° and 53°, respectively [12].

Conclusions

The measurements have shown that the wettability of the surface of Al can increase or decrease depending on the type of treatment to which it is subjected. High wettability is obtained using laser ablation, sand blasting and acid attack as a function of treatment time. Low wettability, ie hydrophobicity, is obtained thanks to the use of mirror surface lapping and ion sputtering.

The surface treatments (lapping, blasting, acid etching, laser ablation, ion implantation) of aluminum surfaces can decrease the contact angles of up to approximately 10% compared to the maximum value for the specular conditions.

The contact angle measured with H_2O appears to be different with H_2O containing nanostructures, therefore, depends on the type of solutions.

The use of NP in solution can decrease the contact angle up to about 50% compared to the solution without NP.

The results show that the contact angle of the solution on aluminum is a function of the type of treatment used and the surface roughness produced.

The roughness of the surface is therefore a fundamental parameter that controls the angle of contact; but the characterization of the surface over which the contact angle change much, must provide for the measurement of hardness, morphology, composition because the oxide on the surface changes the properties of the material.

All treatments presented are simple, not expensive and can be applied with success to control the morphology and the chemical-physical characteristics of the surfaces of Al.

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